# RETAINING FLEXIBILITY IN A TIME OF CHANGE AND VARIABILITY

Matt Shanahan[1]
[1]RM Consulting Group, Bendigo, VIC (matthews@rmcg.com.au)

ABSTRACT

Accurate water balance modelling underpins all successful recycled water schemes. Typically, a standard period of historic rainfall and evaporation data has been used to model the scheme requirements. However, climate change, and the recent drought and flooding experienced across much of Australia questions whether the standard period of data will adequately capture future climate variations. The risk is that infrastructure investments based on the standard data alone will not be appropriate for the future climate. This paper looks at recent changes to the approach of water balance modelling from a standard historic climate model, to a more sophisticated tool that can consider various climate scenarios and be used to guide strategic planning and investment.

## INTRODUCTION

Accurate water balance modelling underpins all successful recycled water schemes. The ultimate aim of water balance modelling is to determine the optimum combination of *storage capacity* and *recycled water use* that is required to strategically manage the volume of wastewater inflows to the treatment plant.

Requirements for storage capacity and recycled water use vary across Australia, and generally range from 50th percentile to 90th percentile containment of inflows (i.e. the ability to manage inflows to the treatment plant in 50% to 90% of years). In years where climatic conditions (i.e. rainfall) see the inflows exceed the capacity of the designed scheme, the scheme managers are able to apply to the controlling authority (e.g. EPA) for the emergency discharge of recycled water from the storage to the environment (e.g. a river or stream).

Typically, historic rainfall and evaporation data for the period 1971 to 1991 has been used to model the scheme requirements. This standard period was chosen because it accounted for variability containing a mix of ‘average’, ‘wet’, and ‘dry’ years and provided a comprehensive data set for the calculations (see Table 1).

However, climate change, and the recent drought and flooding experienced across much of Australia has warranted a review of the approach to water balance modelling. The theory is that the standard period of data will not adequately capture the variations in climate that may be experienced in the future, and therefore, schemes will be designed with inadequate infrastructure (i.e. storage and recycled water use). This could lead to increased discharges to the environment (if built too small), or unnecessary capital expenditure (if built too large).

Increasingly, recycled water managers are required to develop flexible systems and solutions that can deal with the extremes of climate change yet meet their environmental and budgeting expectations.

This paper looks at recent changes to the approach of water balance modelling, from a standard historic climate data model, to a more sophisticated tool that can consider various climate scenarios and be used to guide strategic planning and investment.

*Table 1: Example 1971 to 1991 rainfall and evaporation data for south-central Victoria*

| Year | Rainfall (mm) | Evaporation (mm) |
|---|---|---|
| 1971-72 | 778 | 1278 |
| 1972-73 | 747 | 1451 |
| 1973-74 | 1105 | 1249 |
| 1974-75 | 704 | 1177 |
| 1975-76 | 768 | 1240 |
| 1976-77 | 876 | 1160 |
| 1977-78 | 587 | 1186 |
| 1978-79 | 777 | 1167 |
| 1979-80 | 688 | 1229 |
| 1980-81 | 715 | 1294 |
| 1981-82 | 655 | 1218 |
| 1982-83 | 428 | 1327 |
| 1983-84 | 847 | 1117 |
| 1984-85 | 558 | 1247 |
| 1985-86 | 828 | 1107 |
| 1986-87 | 967 | 1106 |
| 1987-88 | 868 | 1114 |

| | | |
|---|---|---|
| 1988-89 | 1208 | 1105 |
| 1989-90 | 851 | 1093 |
| 1990-91 | 671 | 1177 |
| Long-term (50-year) average | 725 | 1162 |

WATER BALANCE MODELLING OVERVIEW

Water balance modelling is used to predict the optimum combination of storage volume and recycled water use that is required to manage a given volume of recycled water (inflow). It is typically used for recycled water irrigation schemes, but can be applied to any recycled water scheme to ensure there is enough storage and demand (i.e. recycled water use) to manage the volume of inflow.

For irrigation schemes, the underlying principle is that recycled water is stored over winter when there is no demand for irrigation, and then utilised during summer when there is demand. This principle is aimed at ensuring the recycled water is beneficially used, as opposed to being discharged to land when there is no irrigation demand and therefore a greater risk of adverse environmental impact.

The water balance model uses historical rainfall and evaporation data (usually obtained from the Bureau of Meteorology, BoM) to simulate the behaviour of the scheme over a defined time period.

As discussed above, the typical time period has been the 20-year period from 1971 to 1991 as it provided a good mix of years. This means that for schemes required to achieve 90$^{th}$ percentile containment of inflows (like Victorian schemes), the model would predict a combination of winter storage volume and irrigation area that can contain the recycled water in 18 of the 20 years modelled. It is noted however, that the model can be adopted to suit any percentile containment (e.g. 50%, 75% etc).

Figure 1 shows an output of the water balance model for a 90$^{th}$ percentile containment scheme.

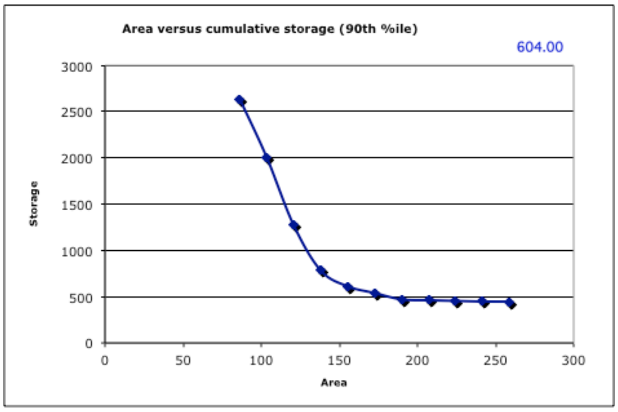


*Figure 1: Example 90$^{th}$ percentile water balance model output*

In this example, the inflow volume is 604 ML/annum, and the optimum combination of winter storage volume and irrigation area to provide 90$^{th}$ percentile containment of the inflows is about 540 ML and 175 ha respectively.

It is noted that Figure 1 shows that there is a range of combinations of winter storage volume and irrigation area that could provide 90$^{th}$ percentile containment.

At one extreme, the storage can be large and recycled water is ‘carried over’ from wet to dry years to enable irrigation demand to be met every year. Under this scenario, the irrigation area is minimised and the ‘security of water’ is absolute, but the winter storage is large (and costly).

At the other extreme, the storage volume can be minimised by increasing the irrigation area. The downside of this is that in most years the irrigated area is ‘under-irrigated’ because there is insufficient water to meet demand.

As a ‘rule of thumb’, it is advised to adopt somewhere in the middle where irrigation demand is met about 80% of the time (i.e. about where the curve in Figure 1 breaks and begins to flatten out). However, this still means that in some dry years only 50% of the irrigated demand is met.

Inflow volume and historical rainfall and evaporation data are the basic building blocks of the model. However, the model also requires a number of other inputs to run:

- average depth of winter storage and treatment lagoons
- crop factor
- pan lagoon factor
- effective rainfall factor
- lagoon seepage rate
- treatment lagoon surface area.

CLIMATE VARIABILITY

Climatic conditions have varied considerably across much Australia over the last 10-15 years, with many areas experiencing the ‘millennium drought’, and then floods. Table 2 below provides the rainfall and evaporation data experienced in south-central Victoria over the period 1998 to 2012 and can be compared to the data provided in Table 1 as evidence of the climate variability experienced.

*Table 2: Example 1998 to 2012 rainfall and evaporation data for south-central Victoria*

| Year | Rainfall (mm) | Evaporation (mm) |
|---|---|---|
| 1998-99 | 649 | 1157 |
| 1999-00 | 803 | 1252 |
| 2000-01 | 880 | 1072 |
| 2001-02 | 375 | 1059 |
| 2002-03 | 411 | 1180 |
| 2003-04 | 609 | 992 |
| 2004-05 | 720 | 1014 |
| 2005-06 | 602 | 1031 |
| 2006-07 | 501 | 1208 |
| 2007-08 | 525 | 1128 |
| 2008-09 | 472 | 1111 |
| 2009-10 | 775 | 1124 |
| 2010-11 | 1133 | 1007 |
| 2011-12 | 824 | 1039 |
| Long-term (50-year) average | 737 | 1146 |

Given these varied climatic conditions and the potential for on-going climate variability due to climate change, the relevance of the 1971 to 1991 climate data to predict future infrastructure investments (i.e. winter storage and irrigation area) has been questioned.

This uncertainty has brought about a change to the water balance modelling approach and has seen the data set used to determine infrastructure requirements expanded.

<u>MODIFIED APPROACH</u>

The modified approach has seen a number of climate scenarios in addition to the 1971 to 1991 period investigated. The climate scenarios have been specifically selected to demonstrate how the scheme would behave under a variable climate, and how the infrastructure requirements alter according to the different climatic conditions.

The climate scenarios have typically included:

- 1971 to 1991 – standard period that is thought to be representative of average conditions
- last 20-years, e.g. 1991 to 2011 – most recent period and involves significant climate variability with a number of very wet, and very dry years
- 1998 to 2008 – very dry period and provides an indication of infrastructure requirements for a dry climate
- 1971 to 2011 – longer term analysis that considers climate variability over a 40-year timeframe
- Medium term climate change – based on data provided by the Victorian Department of Sustainability and Environment (aligns with work conducted by the CSIRO and BoM) and applied to the 1971 to 1991 data.

Table 3 below shows the average rainfall and evaporation data for each 20-year scenario described above. This data is again for the south-central region of Victoria.

*Table 3: Example 1998 to 2012 rainfall and evaporation data for south-central Victoria*

| Scenario | Average Rainfall (mm/annum) | Average Evaporation (mm/annum) |
|---|---|---|
| 1971 to 1991 | 781 | 1202 |
| 1991 to 2011 | 694 | 1086 |
| 1998 to 2008 | 607 | 1107 |
| 1971 to 2011 | 737 | 1144 |
| MCC* 1971 to 1991 | 710 | 1248 |

*MCC = medium-term climate change

It is noted that the long-term averages for this particular site are provided in Table 1, being 725 mm/annum rainfall and 1162 mm/annum evaporation.

If you were to simply analyse the averages provided in Table 3, it would appear that the periods of 1971 to 1991 and 1991 to 2011 are somewhat similar and may produce similar infrastructure recommendations. However, the variable climate of the period 1991 to 2011 makes it quite difficult to model. There is a sequence of very wet years in the early to mid 1990s (see Figure 2) that means that the winter storage is unable to empty, which results in high predictions of winter storage and irrigation area combinations (the 90$^{th}$ percentile requirement for Victorian schemes contributes to this).

By comparison, the other 20-year periods have a ‘good spread’ of wet, dry and average years (relative to the scenario being considered), which allows the winter storage to regularly fill and empty, and produces a much more intuitive combination of irrigation area and winter storage.

The difference between the 1991 to 2011 period and other periods modelled is best illustrated by Figures 2 and 3 below.

Note: in the examples provided in Figures 2 and 3, a minimum winter storage volume of 50 ML is retained at all times to protect the integrity of the winter storages clay liner (i.e. the storages are effectively empty when there is 50 ML in store).

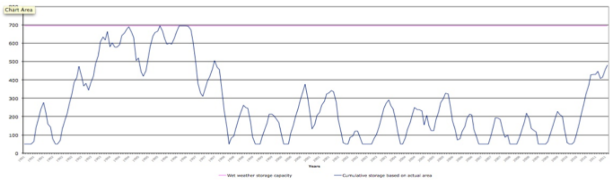

*Figure 2: Winter storage filling and emptying for the 1991 to 2011 period*

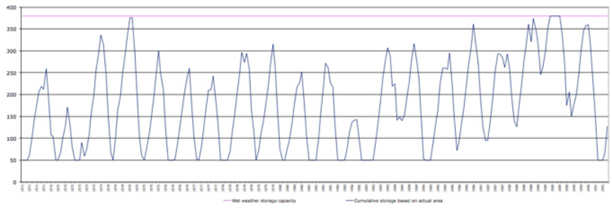

*Figure 3: Winter storage filling and emptying for the 1971 to 1991 period*

The result is that the 1991 to 2011 period produces much higher 90th percentile irrigation area and winter storage volume recommendations than the other climate scenarios considered. This is quite the opposite to what was originally expected, given that this 20-year scenario includes the millennium drought. The key learning here is that assumptions can be dangerous and that the water balance model should be used to really understand the impact of differing climates on the recycled water scheme. The water balance model is able to neatly and efficiently interrogate multiple sets of climate data and show the impact of varying climatic conditions on the scheme and should be used for this purpose.

With the use of the water balance model, it is therefore possible to analyse the five separate 20-year climate scenarios and conclude the following:

- The 1991 to 2011 period provides winter storage and irrigation area combinations that best represent what wet climatic conditions may look like in the future
- 1971 to 2011 average to wet conditions
- 1971 to 1991 average conditions
- medium term climate change 1971 to 1991 average to dry conditions
- 1998 to 2008 dry conditions.

This outcome may or may not be the same for other schemes around Australia. This is not the issue. The key point is that the water balance model enables the scheme manager to analyse a range of different scenarios and decide upon which scenario or scenarios can be used to best inform the scheme.

Following the review of the water balance data, and given the uncertainty of the current and future climate, it seems high risk to base the winter storage and irrigation area requirements for the example provided on one set of climate data alone. Even though the above analyses suggest that the 1971 to 1991 period is still representative of what average climatic conditions may look like into the future, all of the climate change predictions for this region are for a drier climate with more hot days and less rainfall. This would suggest that the historical average for this site will not be the average going into the future. Yet, the site has just come off one of the wettest years on record.

This uncertainty suggests that the winter storage and irrigation area recommendations should be optimised across the range of data analysed. This approach was adopted and is discussed in more detail below.

## WATER BALANCE RESULTS

For the example provided in this paper, the water balance model was run according to the climate scenarios described above, and for a range of inflow volumes:

- current day
- projected +25 years
- projected +50 years.

These inflow volumes allowed the scheme manager to understand the short, medium and long-term infrastructure requirements. This was an important consideration, as the scheme manager would likely need to purchase additional land if the water balance recommended winter storage volume and irrigation area in excess of the schemes current infrastructure. If land does need to be purchased, it is likely to be more efficient and cost effective to buy a larger parcel of land that is capable of handling the +25 or +50 year requirements, as opposed to buying enough land to cater for the next 10 years only, and then adding to it in the future.

In all situations, the water balance modelling should account for a range of inflow volumes that provides the scheme manager with an indication of the size of infrastructure requirements over the short, medium and long-term.

The water balance model results for the 5 climate and 3 inflow scenarios considered are summarised in Tables 4, 5 and 6.

Note: for ease of comparison, a common irrigation area has been adopted for each of the scenarios considered.

*Table 4: Water balance results – current day inflows (370 ML/annum)*

| Scenario | Irrigation area (ha) | Winter storage (ML) |
|---|---|---|
| 1971 to 1991 (ave.) | 81 | 381 |
| 1991 to 2011 (wet) | 81 | 692 |
| 1971 to 2011 (ave. to wet) | 81 | 452 |
| 1998 to 2008 (dry) | 81 | 341 |
| MCC 1971 to 1991 (ave. to dry) | 81 | 359 |

*Table 5: Water balance results +25 years inflow (890 ML/annum)*

| Scenario | Irrigation area (ha) | Winter storage (ML) |
|---|---|---|
| 1971 to 1991 (ave.) | 196 | 773 |
| 1991 to 2011 (wet) | 196 | 1513 |
| 1971 to 2011 (ave. to wet) | 196 | 981 |
| 1998 to 2008 (dry) | 196 | 719 |
| MCC 1971 to 1991 (ave. to dry) | 196 | 760 |

*Table 6: Water balance results +50 years inflow (2171 ML/annum)*

| Scenario | Irrigation area (ha) | Winter storage (ML) |
|---|---|---|
| 1971 to 1991 (ave.) | 478 | 1779 |
| 1991 to 2011 (wet) | 478 | 3540 |
| 1971 to 2011 (ave. to wet) | 478 | 2307 |
| 1998 to 2008 (dry) | 478 | 1676 |
| MCC 1971 to 1991 (ave. to dry) | 478 | 1749 |

Analyses of the water balance results concluded that future infrastructure investment for this site should be based on the 3 following climate scenarios:

- average: 1971 to 1991
- average to wet: 1971 to 2011
- average to dry: medium term climate change, 1971 to 1991.

The other two climate scenarios were excluded from the recommendations for the following reasons:

- wet: 1991 to 2011 – the water balance predictions for this scenario recommend infrastructure that is conservatively high, especially given the potential for climate change, and therefore the potential for this scenario to lead to the construction of infrastructure beyond what will actually be needed
- dry: 1998 to 2008 – the results from this 10-year period recommend infrastructure that is conservatively low and there is no confidence that the recommendations from this scenario will consistently provide 90$^{th}$ percentile containment of inflows into the future.

The exclusion of these two climate scenarios from the remainder of the project meant that the 1971 to 1991 period would still provide recommendations on what infrastructure requirements under average conditions would look like, but the 1971 to 2011 data would now be the wettest scenario considered, and the medium-term climate change scenario the driest.

This analyses and discussion is simply reinforcing the point that the water balance model can help scheme managers to make sense of a range of potential climate scenarios, and select the best mix of data to strategically plan for and guide future infrastructure investment.

## STRATEGIC PLANNING

The water balance modelling data is useless unless it is used in a meaningful way. For the case study provided in this paper, the outcomes of the water balance modelling have been used to strategically plan upcoming infrastructure investment.

The best strategic plans use a series of very simple, yet very clear principles to drive action. In this case, it was decided that the combination of winter storage and irrigation area investment must:

- provide EPA 90$^{th}$ percentile containment of inflows – this is a legal obligation
- minimise risk to the scheme manager by being flexible/adaptive to a variable climate
- be cost effective, i.e. minimise unnecessary capital expenditure where appropriate
- be practical, e.g. it can be more efficient and cost effective to build a 250-300 ML winter storage that will meet the requirements of the

scheme for the next 15-20 years (medium-term), rather than a series of 100 ML winter storages every 5 or so years.

Analyses of the water balance results show that this particular scheme needs in the order of another 650 ML of winter storage and 110 ha of irrigation area to meet the +25 years inflow requirements. The additional winter storage is needed as a priority before the additional irrigation area.

This is a substantial increase in infrastructure, so it was decided to split the investment in two. That is, two lots of 325 ML of winter storage and 55 ha of irrigation area.

Construction of the additional infrastructure in this way will enable the scheme to achieve the following:

- first 325 ML of winter storage and 55 ha of irrigation area:
  - it will provide enough infrastructure to achieve 90$^{th}$ percentile containment of inflows for the next 19 years under dry conditions
  - for the next 15 years under average conditions
  - and for the next 9 years under wetter conditions.
- second 325 ML of winter storage and 55 ha of irrigation area:
  - it will provide enough infrastructure to achieve 90$^{th}$ percentile containment of inflows for the next 31 years under dry conditions
  - for the next 25 years under average conditions
  - and for the next 18 years under wetter conditions.

It was recommended that the works be staged as follows:

- construct the first 325 ML of winter storage ASAP
- the first 55 ha of irrigation area in the next 5 years
- the second 325 ML of winter storage in the next 15 years
- and the second 55 ha of irrigation area in the next 20 years.

This staging of works was based on the average climatic conditions, and was to be used as a guide only. The scheme manager is required to monitor future climatic conditions and respond appropriately. For example:

- if average climatic conditions occur, adopt the staging of works as specified
- if it's dry, construction of the first 55 ha of irrigation area can be delayed by 4 years; the second 325 ML winter storage by about 3 years; and the second 55 ha of irrigation area by 4 years
- if it's wet, the first 55 ha of irrigation area needs to be constructed immediately (i.e. at the same time as the first 325 ML winter storage); the second 325 ML winter storage comes forward by 6 years and the second 55 ha of irrigation area by 5 years.

This strategy is about planning for the average to dry conditions, but being capable of handling a decent amount of wet years should they eventuate. This strategy was purposefully selected because it aligns with the strategic plan principles adopted at the start:

- it will provide 90$^{th}$ percentile containment of inflows for a minimum of the next 9 years under all climate scenarios considered
- it provides flexibility under a variable climate – if wet conditions are experienced over the next 5-10 years, the scheme manager has the option to again construct more irrigation area and winter storage. However, if dry conditions persist, the scheme manager will have built enough winter storage and irrigation area to provide 90$^{th}$ percentile containment over the next 20-30 years, which is still an appropriate timeframe (i.e. not too far into the future).
- it minimises the risk of unnecessary capital expenditure – the scheme manager can continue to monitor climate conditions over the next 5-10 years, and if required, build more winter storage and irrigation area as it is needed. If increases to the irrigation area and winter storage are not required, the capital has not been spent and therefore wasted.
- 55 ha of irrigation area and 325 ML of winter storage are practical sized developments that can be used to identify suitable parcels of land for purchase.

This thinking and strategy would not have been possible if the standard 1971 to 1991 period only was adopted. The additional modelling undertaken has allowed a more strategic approach to water balance modelling to be conducted and for the scheme manager to devise a program of works that will allow them to sustainably manage the recycled water under a range of conditions.

## CONCLUSION

Recycled water balance modelling has historically relied upon data from the period 1971 to 1991 to guide infrastructure investment. Whilst this period still provides robust data for analysis, and in many cases will continue to provide accurate results on what can be expected under 'average' climatic conditions, the climate variability experienced over the last 15 years and potential for future climate changes warrants the expansion of water balance modelling approach to consider a range of potential climate scenarios.

Like all projects involving the complex analysis of data, the data on its own is useless unless it is used in a meaningful way. The expansion of the water balance model to include a number of differing climate scenarios enables data from the modelling to be used to strategically plan future infrastructure investments and minimise the risk of undersizing or oversizing developments.